DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

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Note: **G-63**

Preliminary Considerations on Machine Requirements for a Neutron-Antineutron Form Factor Experiment at Frascati

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Introduction

The possibility of an experiment dedicated to the neutron-antineutron form factor measurement in DAΦNE is being investigated. A preliminary estimate of the minimum changes needed in DAΦNE for the experiment feasibility is here presented. The requirements are:

Maximum energy: 1.2 GeV per beam
Peak luminosity: 10^{32} cm^{-2} sec^{-1}
Range of energy to be investigated: from 510 MeV to 1.2 GeV
Integrated luminosity: 3 fbarn^{-1}

Even if the possibility to run also at the Φ-energy is taken into account, optimizing the performance in the low energy range is not considered.

To minimize the changes it has been decided to inject at 510 MeV, and ramp the collider up to the operation energy, in order to keep the present injection system unchanged (Accumulator, transfer lines, injection septa and injection kickers), even in case the Linac energy is upgraded to comply with the SPARXINO project.

As already described in [1], many of the present DAΦNE systems, such as feedbacks and diagnostics, are compatible with an operation at higher energy and lower current. In the following only those parts of the collider needing un upgrade will be addressed.

An evaluation of how many of the present magnetic elements can be reused is still missing, since it needs a more precise calculation of the optics, which will depend on the detector characteristics. A preliminary estimate indicates that about 80% of the total number of quadrupoles, all sextupoles and all correctors are compatible with the energy upgrade.

Energy

The main changes in the machine concern the dipoles and the Interaction Region.

We have discarded the possibility of keeping the present vacuum chamber, since this solution would limit the maximum attainable energy to ≈ 1 GeV per beam, unless superconducting dipoles were used, which has not been foreseen up to now. In fact the preliminary design of the dipoles presented at Alghero was based on Permendur poles, slightly larger bending radius (1.53 instead of the present 1.4 m), 7 cm gap compatible with the vacuum chamber height, reasonable field quality and maximum field of ≈ 2.2 T, allowing to reach only 1.01 GeV per beam [2].

Therefore we propose to modify the vacuum chamber and use normal conducting dipoles, with a bending radius ρ = 2.22 m and operating field B = 1.8 T, i.e. 1.2 GeV per beam. The dipole field will change between 0.77 T and 1.8 T during the ramping process. A dedicated paragraph describes the preliminary design of such a dipole.

Assuming to run the collider with only one Interaction region, keeping the layout of the ring as it is now, the dipoles around the present second IR must have different angles to close the ring. A vertical separation scheme in the 2nd crossing point must be included.

The IR design will be based on SC quadrupoles, as those developed at Brookhaven [3] for the ILC final focus, HERA, BEPC II , etc.. A first design will be done following the not yet defined parameters of the detector that will be used for the experiment.

Luminosity

Assuming to keep the present RF system and wigglers, the luminosity is essentially limited by the maximum storable current per ring, which is of the order of 0.5 A.

The natural bunch length at 1.2 GeV, considering a lattice with the present wigglers and the above described dipoles, is of the order of 2 cm and β^*_y is therefore 2 cm.

The luminosity can be written as:

$$L = \frac{N_b f_o}{4\pi} \frac{N^2}{\varepsilon\sqrt{\beta_x^* \beta_y^* k}}$$

With:

Revolution frequency = $f_o = 3.07 MHz$

Horizontal emittance = $\varepsilon = 0.6$ *mm.mrad*

Horizontal betatron function at IP = $\beta_x^* = 1m$

Vertical betatron function at IP=$\beta_y^* = 2cm$

Emittance coupling = $\kappa = 0.007$

the required luminosity is obtained when the number of bunches, N_b, and the number of particles per bunch, N, satisfy:

$$N_b N^2 = 2.9 * 10^{22}$$

The current per bunch and the total current are shown in Fig. 1, as a function of the number of bunches. Recalling that the beam-beam tune shifts are given by:

$$\xi_x = \frac{r_e}{2\pi\gamma} \frac{N}{\varepsilon_x}$$

$$\xi_y = \xi_x \sqrt{\frac{\beta_y^*}{\kappa \beta_x^*}}$$

we see that the they are always below the value already obtained in DAΦNE, as shown in Fig. 2.

We take as nominal N_b value 30 bunches, corresponding to 0.5 A per ring, which fits the existing rf and feedback system.

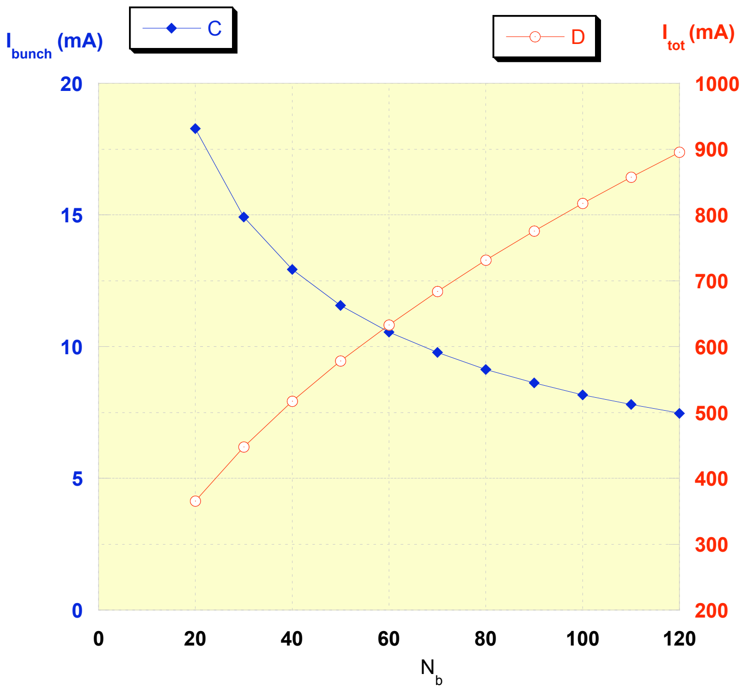

Figure 1 – Current per bunch and total current for L = 1 10^{32} cm^{-2} sec^{-1}

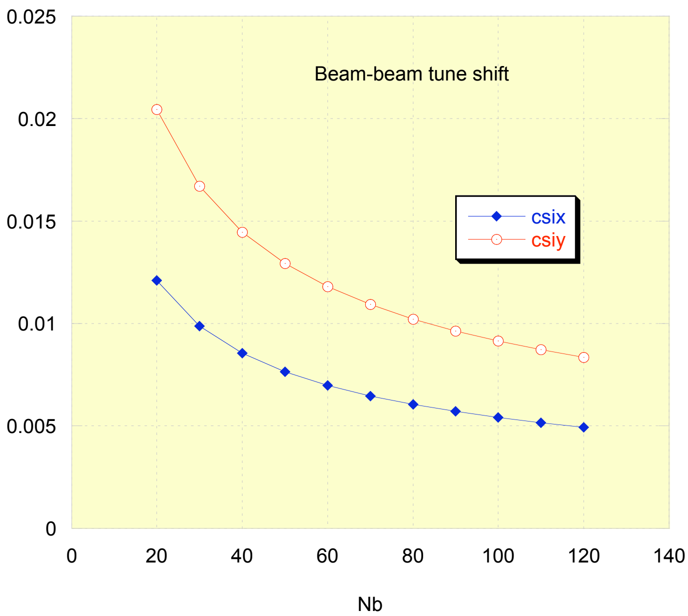

Figure 2 – Corresponding beam-beam tune shift

Damping

The contribution of the dipoles to the synchrotron radiation integral I_2 is

$$I_{2d} = \oint \frac{ds}{\rho^2} = \frac{2\pi}{\rho} = 2.83 m^{-1}$$

at any energy.

With the present wigglers on at constant field ($B_{max} = 1.8$ T)

$$I_{2w} = \frac{2.55}{E(GeV)} m^{-1}$$

and the betatron damping time τ_x as a function of the energy is shown in Fig. 3 (neglecting the contribution from I_4). Both damping times with wigglers on-off are plotted, together with I_2 (wigglers on). Let's recall that now, at 0.51 GeV, τ_x is 37 msec. There will be therefore an increase of the damping time due to the different dipoles, meaning that at low energy the collider will be more critical than now.

The energy loss per turn is shown in Fig. 4 for wigglers off-on. The main parameters of the collider are given in Table I.

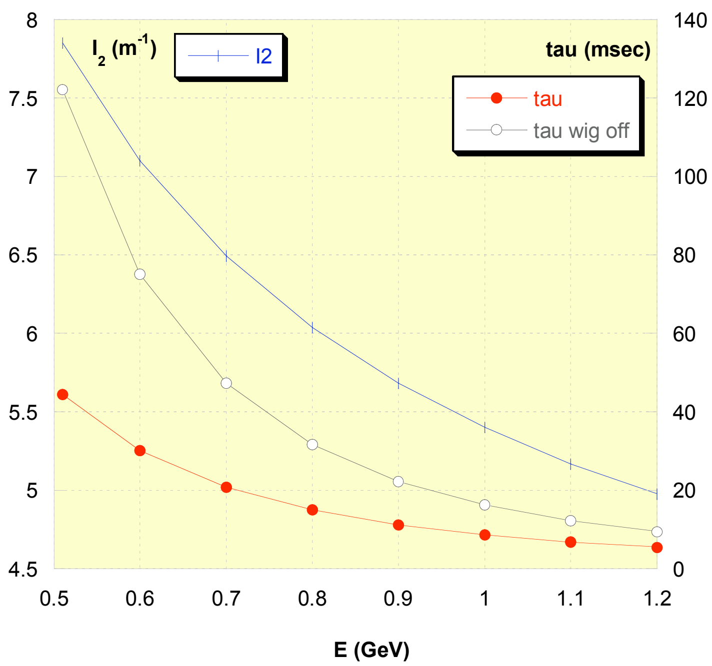

Figure 3 – I_2 with wigglers on (left axis) and betatron damping times (right axis) with wigglers on - off versus energy.

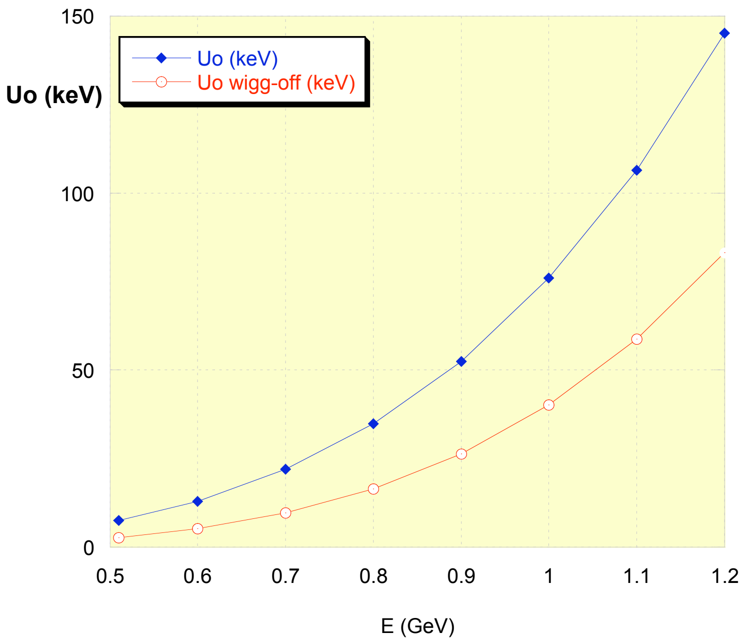

Figure 4 – Energy loss per turn with wigglers on and off

Table I - Main DAΦNE parameters for 1.2 GeV operation

Maximum energy	E_{max}	GeV	1.2
Luminosity at E_{max}	L	$cm^{-2}\ sec^{-1}$	10^{32}
Injection energy	E_{inj}	GeV	0.51
Current	I	A	0.5
Number of bunches	N_b		30
Particles per bunch	N		$3.1\ 10^{10}$
Horizontal emittance	ε	mm mrad	0.6
Horizontal beta at IP	β_x^*	m	1
Vertical beta at IP	β_y^*	cm	2
Coupling	κ		0.007
Natural energy spread at E_{max}	σ_E/E		$6.6\ 10^{-4}$
Momentum compaction	α_c		0.014
Natural bunch length at E_{max}	σ_L	cm	1.9
Rf frequency	f_{rf}	MHz	368
Peak rf voltage	V	MV	0.30
Max RF power per beam	P	KW	75

DAΦNE lattice

A preliminary estimate of the DAΦNE optics with the 2.2 m bending radius dipoles and wigglers on and off has been done. Since the IR is not yet defined the optics is symmetric with two 'detuned' IR sections: a low-beta insertion can be easily introduced once the detector characteristics will be defined.

The dipoles are all sector magnets. Due to their larger longitudinal dimensions, the skew quadrupoles now placed near the dipoles must be displaced with respect to the present position.

One of the main differences with the present optics is the value of the synchrotron radiation integral I_5. In fact due to the smaller I_2, and to the higher energy, keeping the emittance similar to the present one requires a much smaller value of the 'invariant'. Let's recall that the emittance is given by:

$$\varepsilon_x = \frac{55}{32\sqrt{3}} \frac{\hbar}{mc} \left(\frac{E}{mc^2} \right)^2 \frac{I_5}{I_2 - I_4}$$

where I_j are the usual synchrotron radiation integrals.

Figure 5 shows the optical functions along the ring for the case of wigglers on.

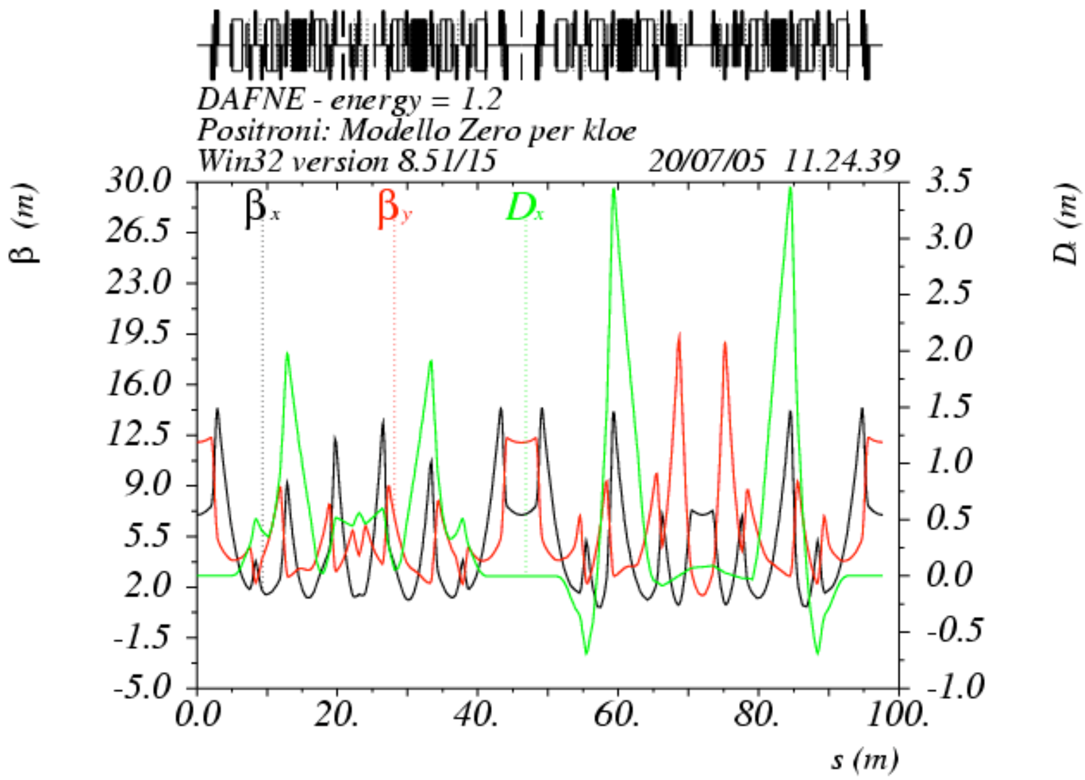

Figure 5 – Betatron and dispersion functions for DAΦNE at 1.2 GeV

RF system considerations

The DAΦNE RF system presently in operation consists of one single cell copper cavity per ring powered by a dedicated 150 kW klystron. The cavity has long tapered beam tubes and damping waveguides attached to the body to minimize the content of High Order Modes (HOMs). Since the cavity cooling system is rated to a maximum cavity wall dissipation of 25 kW, the maximum achievable RF voltage is V_{RF} = 300 kV. The klystron RF power in excess is available to compensate the beam losses.

The DAΦNE RF system does not require major upgrades to satisfy the requirements of a 1.2 GeV/ring collider with the previously specified performances.

The bunch current threshold for microwave instability is higher than the nominal bunch current at the maximum energy for the present positron ring impedance, since it is proportional to the energy.

The most significant parameters related to the RF system for the proposed machine upgrade are summarized in Table II.

Table II - Parameters related to RF system

Frf [MHz]	368.2
RF voltage [kV]	300
Momentum compaction	0.014
Radiation losses [keV/turn]	150 (wigglers ON) 80 (wigglers OFF)
Energy spread	$6.6 \cdot 10^{-4}$
Energy acceptance	$6.7 \cdot 10^{-3}$ (wigglers ON) $9.0 \cdot 10^{-3}$ (wigglers OFF)
Cavity wall power [kW]	25
RF power available for beam [kW]	120
Max. beam current [A]	0.8 (wigglers ON) 1.5 (wigglers OFF)
Bunch natural length [mm]	19
Bunch current lengthening threshold [mA] (Boussard criterion @ Z/n = 0.5 Ω)	30

1.8 T Normal Conducting Dipole

A very preliminary design of a normal conducting dipole magnet, for the DAΦNE Upgrade is presented in the following just to understand the feasibility of such a magnet.

The Input Data are:

Beam Energy 1.2 GeV
Maximum Magnetic Field 1.8 T
Minimum Magnetic Field 0.77 T
Magnet Full Gap 30 mm

Since the gap is only 30 mm, the solution of a H shaped dipole magnet must be chosen to allow the coil mounting. A C shaped solution, with detachable poles, would be rather complicated from the mechanical point of view and, since the magnet must ramp up from 0.77 to 1.8 T, the connecting bolts may represent a problem from the eddy currents point of view. It should be carefully studied evaluating the requested ramp up/down time, not known at the moment. At this stage no optimization of the magnetic field profile has been done. This will be an issue to be studied in the next future, together with a much more complete optimization of all the magnetic and electric parameters. Also 3D simulation must be performed in the future, to better evaluate the magnetic field profile at the magnetic field (1.8T) requested at the centre of the magnet gap.

A very special asymmetric vacuum chamber must be studied for the dipole magnets. It should have a suitable synchrotron light absorber system, including cooling and distributed pumping system.

Figure 5 shows the result of Poisson simulation. The magnetic field at the gap centre is a little higher than the requested one. The fringing field outside the magnet is reduced to less than 10 Gauss at 12 cm from the external magnet body. This value should be sufficient to avoid any cross-talk between the two rings.

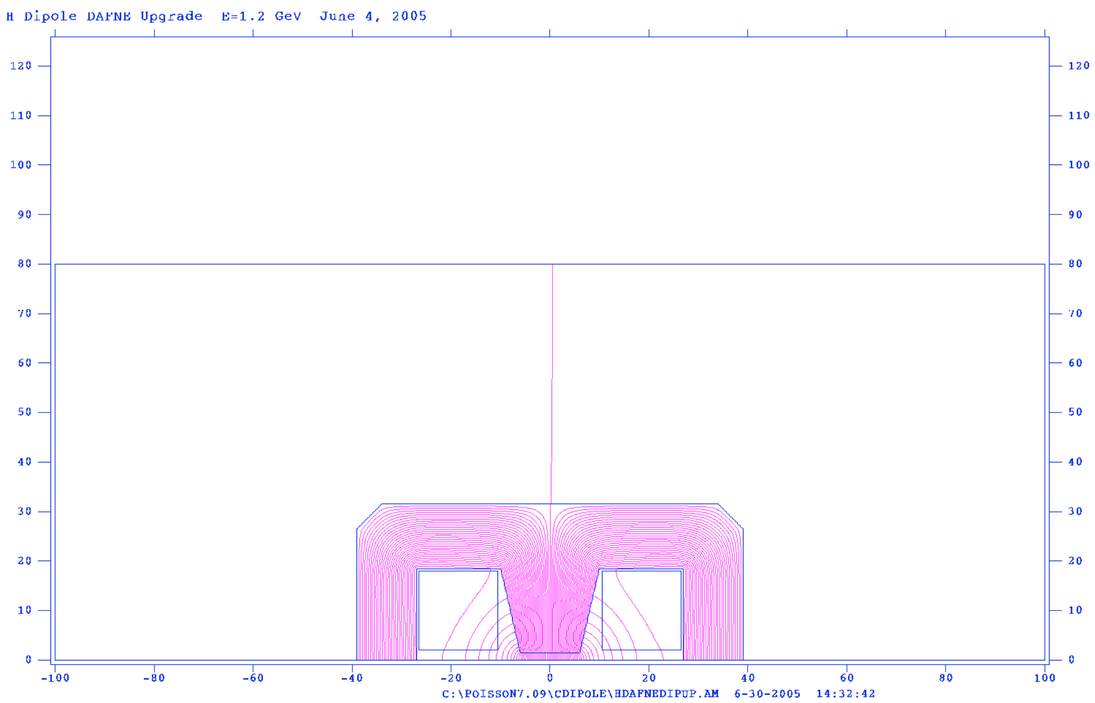

Figure 5 – 1.8 T Dipole Magnet, POISSON simulation output.

Figure 6 shows the magnetic field profile on the horizontal symmetry plane. The magnetic field on the return iron legs is maintained below 1.5 T to reduce the external fringing field.

Figure 7 shows a zoom of the magnetic field profile in the gap of the magnet.

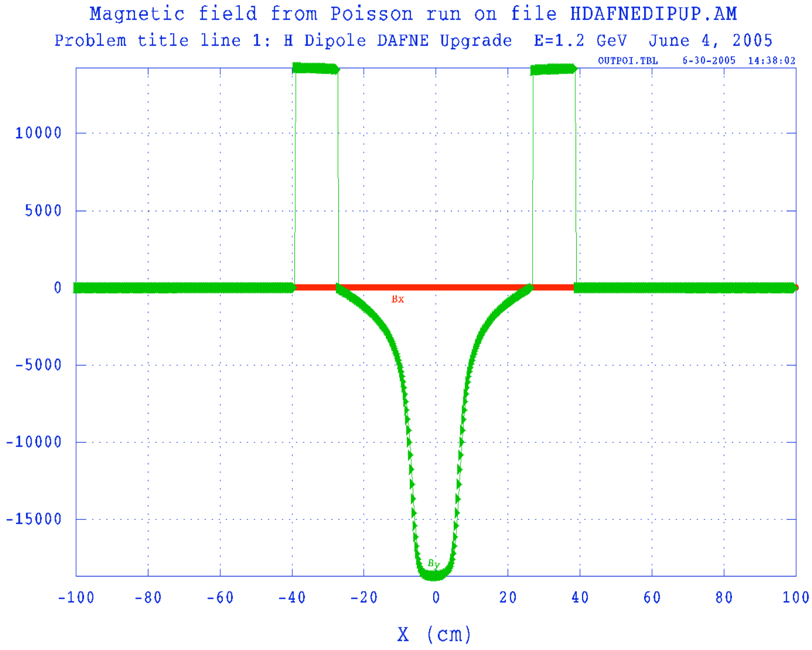

Figure 6 – 1.8 T Dipole Magnet, Magnetic Field profile on the horizontal symmetry plane.

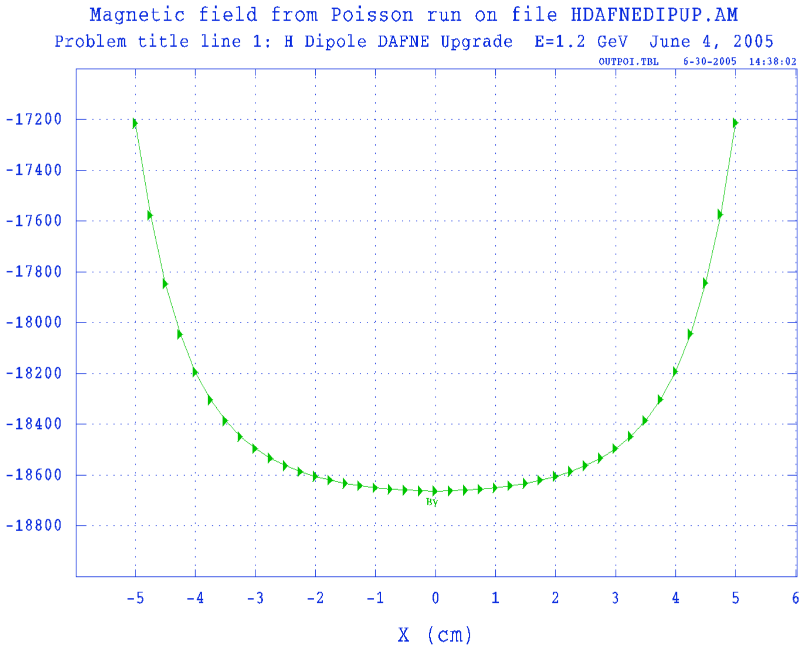

Figure 7 – 1.8 T Dipole Magnet, Magnetic Field profile in the gap region.

Figure 8 shows the magnetic field profile on the horizontal symmetry plane at the minimum field level of B = 0.77 T.

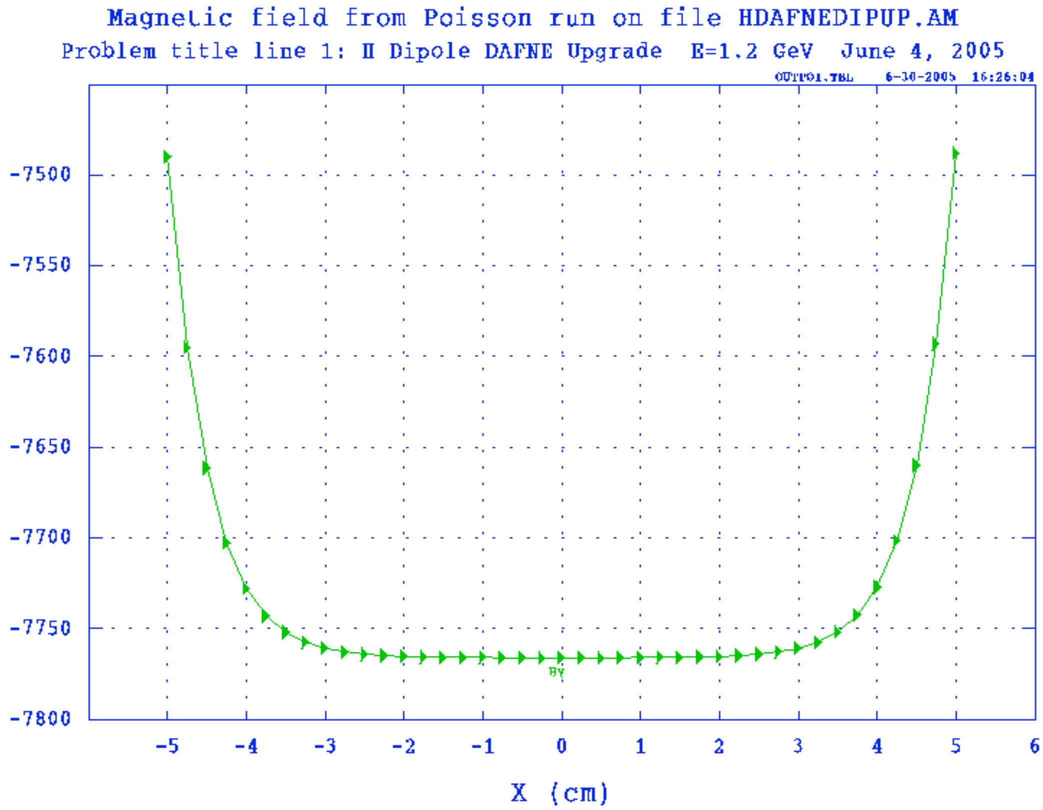

Figure 8 – 0.77 T Dipole Magnet, Magnetic Field profile in the gap region.

The main magnetic, electric and mechanical parameters of the magnet are listed in table III.

The values listed in table I confirms a conservative design of the 1.8 T Dipole Magnet that needs to be further on optimized.

The existing power supply seems well to fulfil the requested voltage and current values. However, it has been designed for steady state operation, then a set of measurements should be accomplished to verify the dynamic performances during the current ramp-up to determine if it effectively can be re-used for the upgraded machine.

A first check of the compatibility of the dipole dimensions with the present DAΦNE layout has been done.

Figure 9 shows a sketch of the 3D DAΦNE layout, with the dipole model. It is preliminary since all the dipoles are represented with the same length corresponding to a bending angle of 45°, and has been used to positively check the transverse compatibility with the present layout.

Table III – 1.8 T Dipole Magnet Parameter List

Dipoles per ring		8	8
Energy	GeV	0.51	1.2
Nominal Field	Tesla	0.77	1.8
Bending Radius	m	2.22	2.22
Magnet gap	mm	30	30
Magnetic length*	m	1.745	1.745
Iron Mechanical Length**	m	1.673	1.673
Overall Mechanical Length**	m	2.195	2.195
Width	m	0.78	0.78
Height	m	0.63	0.63
Pole width at the gap	m	0.12	0.12
Pole width at the yoke	m	0.2	0.2
Nominal A*turn per pole	A	9400	27500
Turn per pole		64	64
Nominal Current	A	147	430
Current Density	A/mm^2	0.63	1.85
Copper Conductor	mm*mm	17.4*17.4	17.4*17.4
Cooling Hole Diameter	mm	9.3	9.3
Magnet Resistance	mΩ	48	48
Magnet Inductance	mH	213	213
Voltage per Magnet	V	7.05	20.64
Power per Magnet	W	1036	8875
Water Circuits per Magnet		4	4
Total Water per Magnet	m^3/s	$2.1*10^{-4}$	$2.1*10^{-4}$
Pressure Drop	MPa	0.16	0.16
Water Speed	m/s	0.8	0.8
Water Temperature Rise	°C	1.2	10
Iron Weight	t		4.5
Copper Weight	t		1.25
Total Voltage pr Ring	V	56.4	165.1
Total Power per Ring	W	8290	71000
Total Water per Ring	m^3/s	-	$1.7*10^{-3}$

* Average value.
** Average estimated value, Parallel end dipole.

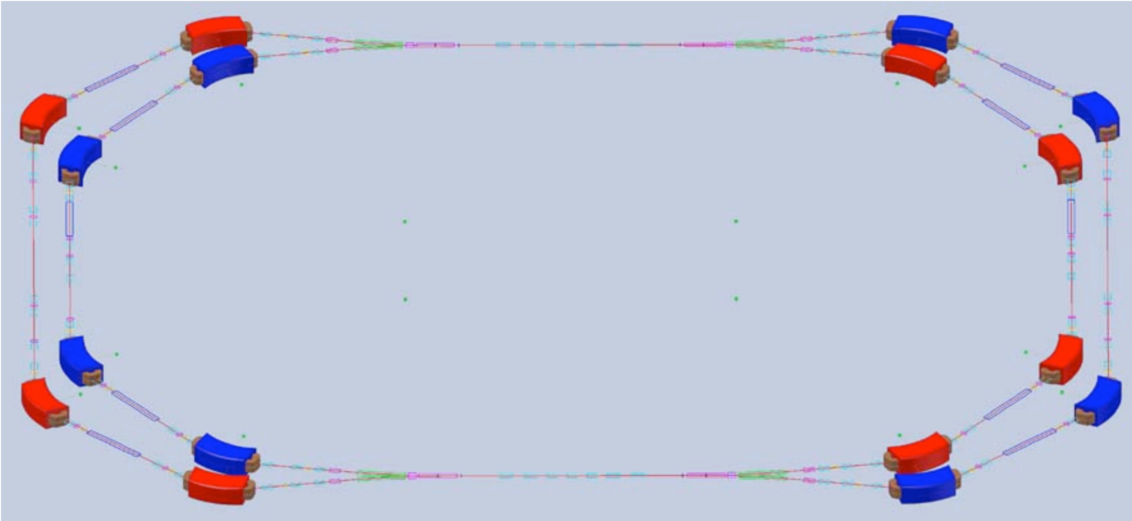

Figure 9 – Preliminary check of the transverse dipole dimensions compatibility with the present DAΦNE layout.

Conclusions

Preliminary considerations on the feasibility of energy upgrade in DAΦNE up to neutron-antineutron threshold is here discussed. The collider operation foresees an energy range from the present value (E = 0.51 GeV per beam) up to 1.2 GeV.

No optimization of the luminosity at the Φ-energy is here considered.

References

[1] G. Benedetti et al.: "Feasibility study of a 2 GeV Lepton Collider at DAΦNE", PAC03 proceedings.

[2] C. Ligi, R. Ricci: Presented at Workshop on $e^+ e^-$ in the 1-GeV to 2-GeV Range: Physics and Accelerator Prospects - ICFA Mini-workshop - Working Group on High Luminosity $e^+ e^-$ Colliders, Alghero, Sardinia, Italy, 10-13 Sep 2003. **eConf C0309101:FRWA003, 2003.**

[3] Brett Parker et al.: "Compact Superconducting Final Focus Magnet Options for the ILC", PAC05 proceedings.